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A Reduced Wind Power Grid Model for Research and Education

Vladislav Akhmatov, Torsten Lund, Anca D. Hansen, Poul Sørensen, and Arne H. Nielsen

Abstract—A reduced grid model of a transmission system with a number of central power plants, consumption centers, local wind turbines and a large offshore wind farm is developed and implemented in the simulation tool PowerFactory (DIgSILENT). The reduced grid model is given by Energinet.dk, Transmission System Operator of Denmark (TSO) for Natural Gas and Electricity, to the Danish Universities and the Risø National Laboratory. Its intended usage is education and studying of interaction between electricity-producing wind turbines and a realistic transmission system. Focus in these studies is on voltage stability issues and on the ride-through capability of different wind turbine concepts, equipped with advanced controllers, developed by the Risø National Laboratory.

Index Terms—wind power, power transmission model, offshore wind farm, ride-through, voltage stability.

I. INTRODUCTION

IN Denmark, more than 20% of the electricity consumption is supplied from wind turbines. In the years to come, the share of wind power in the Danish electric power supply will increase due to commissioning of large offshore wind farms and re-powering, e.g. replacement of small, elder wind turbines by large, advanced ones.

Electricity-producing wind turbines must comply with the grid code of the national TSO with a specific focus on the ride-through solution, e.g. when the wind turbines do not disconnect from the grid at specified short-circuit faults and support voltage re-establishment [1,2]. Furthermore, the control of the wind turbines may not start interacting with the control of central power plants or other equipment in the transmission power grid, unless required in the specifications.

Successful incorporation of wind power into transmission power grids requires detailed knowledge about the electricity-producing wind turbines and the power grid itself. Advanced ride-through solutions are the result of intensive research and development within the wind technology.

The wind turbine manufacturers and the research centers may already have validated models of electricity-producing wind turbines of existing as well as future concepts.

Dynamic stability investigations and evaluation of the ride-through solutions are a part of the grid-connection process of a significant amount of wind power. A common question of such stability investigations is what happens in the transmission power grid with a significant amount of wind power when a short-circuit fault occurs [3].

A realistic transmission power grid is characterized by a voltage and a frequency, which are not fixed to their respective rated values, but may fluctuate when the grid is subject to a disturbance. When a short-circuit fault is cleared, the voltage and the frequency in the transmission power grid must be re-established by the control of central power plants, other equipment, for example dynamic reactive compensation units, and large offshore wind farms.

The transmission grid models, including the control of the power plants and the large offshore wind farms, are maintained by the power grid companies and the national TSO, may often be complex with a lot of details, contain confidential data and not always shareable with any interested party.

There is a lack of realistic, but reduced, models of transmission power grids with grid-connected wind turbines, which are shareable with all interested parties, applicable for education and research projects and for demonstration of the ride-through solutions of the wind turbines.

This paper presents a generic, reduced model of a transmission power grid of the Danish TSO Energinet.dk and its application to evaluation of wind turbines models and their advanced controllers, developed by the Risø National Laboratory, and to education at the Technical University of Denmark.

As the share of wind power in the grid is significant nowadays, it is termed a reduced wind power grid model. The model is implemented in the simulation tool PowerFactory (DIgSILENT). People who are interested in using the model can acquire a PowerFactory data file by writing an email to the first author.

II. WIND POWER GRID MODEL

The reduced model of the transmission power grid with a large offshore wind farm is shown in Fig. 1.

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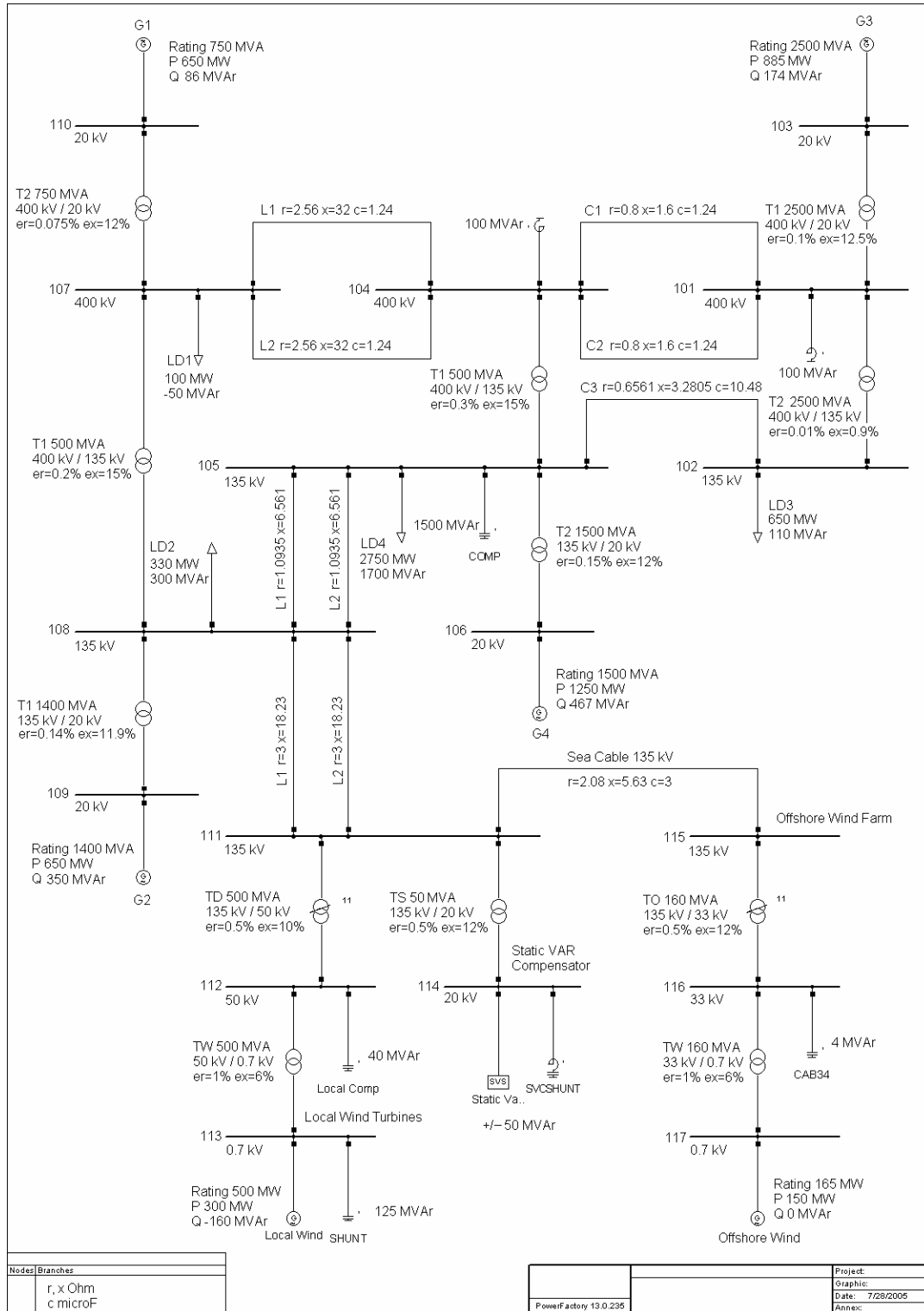


Fig. 1. Reduced wind power grid model of Energinet.dk for research and education.

The model contains 17 buses with voltages from 0.7 kV to 400 kV, 4 central power plants with excitation and governor control, a Static VAR Compensator (SVC), several consumption centers, a lumped equivalent of local wind turbines and a single-machine equivalent of the large offshore wind farm [4]. The load flow solution gives a snapshot of the grid model prior to an investigated event and is used for

initialization of dynamic models of all the controllers.

A. Central Power Plants

The central power plants, G1 to G4, are equipped with synchronous generators with round rotors. The main data of the generators with their control equipment models are described in Appendix A.

B. Wind Turbines

The local wind turbines are all at 60% wind, which implies that the active power produced by the local wind turbines is 60% (e.g. 300 MW) of the rated power of 500 MW.

The local wind turbines are fixed-speed and equipped with conventional asynchronous generators.

The buses from 115 to 117 are allocated to the large offshore wind farm. The single-machine equivalent of the wind farm is connected to the bus 117, has a rating of 165 MW and is close to the rated operation point (150 MW).

The large offshore wind farm in this reduced grid model is with fixed-speed, active-stall controlled wind turbines equipped with conventional asynchronous generators. This is similar to the Danish offshore wind farm commissioned in the year 2003 at Nysted/Rødssand.

Fig. 2 shows the block diagram model of the large offshore wind farm. The wind farm generator is modeled applying the standardized asynchronous generator model of the simulation tool, whereas the shaft system, the active-stall control and the protective system are modeled by the user-written models.

The same model approach is applied for the local wind turbines, except of the active-stall control.

The shaft system is represented by the two-mass model to simulate torsion oscillations in the shaft systems of the wind turbines [3]. Fig. 3 gives the block diagram implementation of the two-mass shaft model, where H_M is the rotor inertia constant, K_S is the shaft stiffness, f_E is the electric frequency, D_M is the rotor damping and the blocks labeled $1/s$ denote integrators. The model inputs, P_m and x_{speed} , are the rotor power and the generator rotor speed, respectively. The model outputs, $mspeed$ and pt , are the rotor speed and the generator shaft power, respectively.

The active-stall control is applied to improve the ride-through capability of the wind farm [5]. This control is modeled in a generic manner with only representation of the relevant functionality. The generic active-stall model does not contain representation of the blade angle to control the rotor power, but controls directly the mechanical power of the rotor. The modeled control procedure is as the following. When the voltage in the on-land connection point (bus 111) drops below 0.7 p.u. for longer than 50 ms, the active-stall control is ordered to reduce the mechanical power of the rotor to 20% of the rated mechanical power [5,6]. The rate of the mechanical power reduction is limited to -0.4 p.u./s, so, from any arbitrary operation point, reaching the required 20% of the rated mechanical power takes less than 2 s.

When the fault is cleared and the monitored voltage has recovered to within the required range, the large offshore wind farm continues operating with the reduced mechanical power for 5 s. and then starts ramping up the mechanical power from the rotor. The ramping rate is limited to 0.2 p.u./s.

The parameters of the wind farm and the local wind turbines are given in Appendix A. The response of the large wind farm model to a transient 3-phase short-circuit fault in the 132 kV system is shown in Fig. 4. The behavior follows the above-described procedure.

C. Static VAR Compensator

The SVC unit has a dynamic range of +/- 50 MVar. It is applied to improve the voltage profile in the on-land connection point of the large offshore wind farm - bus 111.

The model description and the main data are given in Appendix A.

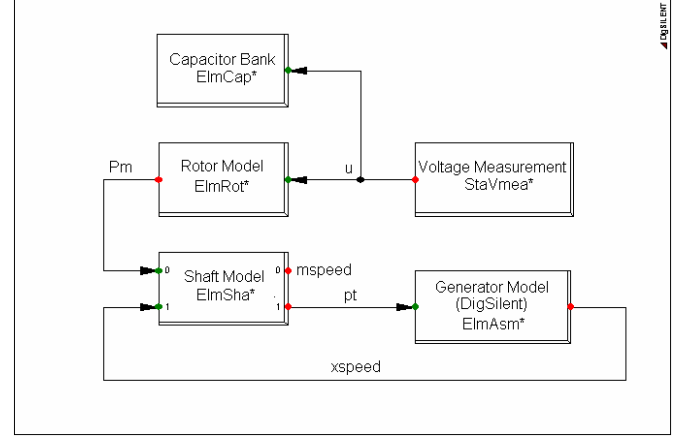


Fig. 2. Composite model of the large offshore wind farm with fixed-speed, active-stall controlled wind turbines equipped with conventional asynchronous generators

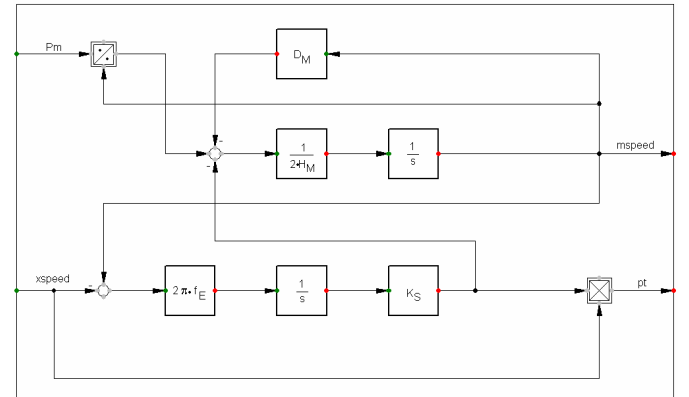


Fig. 3. Implementation of the two-mass model in the block diagram technique of the tool PowerFactory.

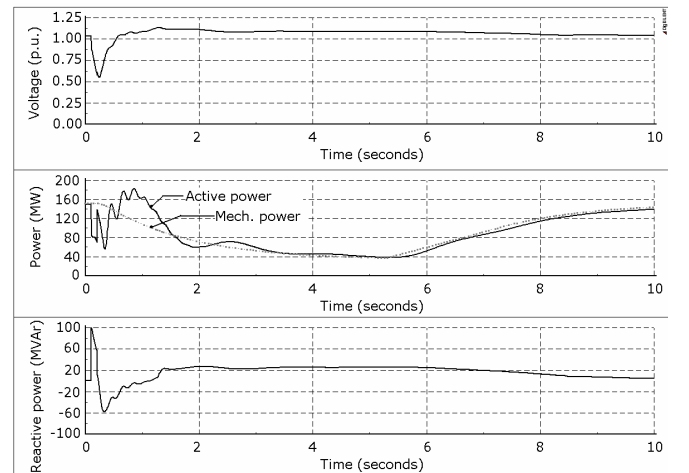


Fig. 4. Response of the large offshore wind farm to a short-circuit fault in the transmission system.

In both cases, it is assumed that the active stall wind farm is not equipped with the fault ride-through control, namely its power reduction control is disabled. The fact that the active stall wind farm, placed in the vicinity of the DFIG wind farm, has no fault ride-through control enabled, has a negative influence on the voltage stability in the grid, implying longer time voltage oscillations in case of no voltage control for the DFIG wind farm.

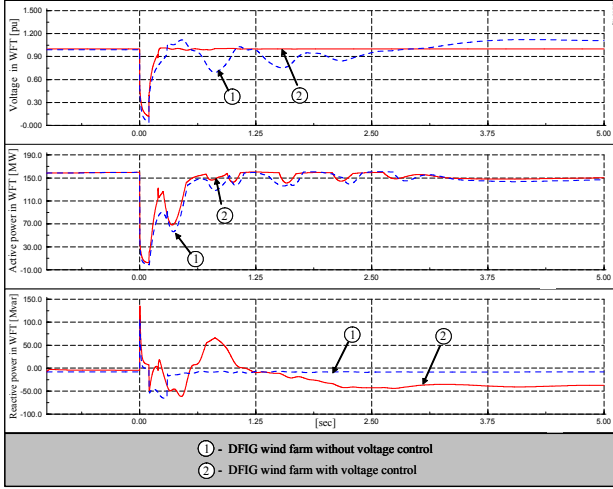


Fig. 6. DFIG wind farm terminal (WFT) - with or without co-ordinated voltage control when the power reduction control of the active stall wind farm is disabled.

As expected, the influence of voltage control is visible both during the fault, when the grid side converter operates as STATCOM and supplies reactive power, and after the disconnection of the crowbar, when the rotor side converter controls the voltage. When no voltage control is enabled, the grid voltage oscillates and stabilizes to a higher voltage level after the fault is cleared. This can be explained both by the reactive power surplus in the system as result of the on-land wind turbines disconnection and by the fact that, as result of the fault clearance (tripping Line 4), the transport of the active power from the wind farms to the grid is done through a higher impedance transmission line. Fig. 6 shows that the existing reactive power surplus in the system is absorbed by the DFIG, when the voltage control is enabled. Note that the DFIG voltage control re-establishes the grid voltage to 1p.u. very quickly without any fluctuations. No significant effect of the voltage control appears on the active power production. However, there it is a slight improvement in active power when voltage control is used. The small “drops” in the power, visible in both cases just after the fault is cleared, correspond to the damped torsional oscillations in the generator speed. The damping controller damps the torsional oscillations appearing in the drive train and in the generator speed, due to the grid fault during few seconds. The initial level of the active power is reached after few more seconds.

DFIG wind farm equipped with voltage control manages thus to re-establish fast the voltage, by controlling the reactive power supply.

IV. THE USE OF THE MODEL IN EDUCATION AT DTU

The model has been used for exercises in the course *Stability and Control in Electric Power Systems* at the Technical University of Denmark. The objectives of the exercises are firstly to illustrate different problems regarding the stability of a realistic power system, and secondly to introduce different analysis methods for stability assessment to the students. Where it is possible, the simulations in PowerFactory are compared to “hand calculations”.

This section shows a few examples taken from an exercise about voltage stability assessment.

A. U/P – curves

The first part of the exercises is to make a so called U/P - plot of the bus bars for the production from the offshore wind park in Fig. 1. In PowerFactory, U/P – curves are made by performing a series of load flows with different production from the wind farm. This task is performed with a so called DPL¹ script, which makes the procedure very flexible.

Fig. 7 shows the effect of increasing the active power production from the offshore wind park when G3 is chosen as slack generator. The voltage on Bus 117 is increasing with higher production up to approximately 110 MW due to the resistance in the sea cable and the transformers. After that it starts decreasing. At a production of 252 MW the SVC reaches its upper limit, and at 286 MW the voltage at the offshore wind farm collapses.

When the production is between 50 MW and 252 MW the SVC is able to maintain a constant voltage in the point of common coupling. Due to the thermal ratings of the cables and transformers, it would not be realistic to inject 286 MW at bus 117, but the U/P plot shows how far away from the stability limit the system is operated at the rated output of the offshore wind park.

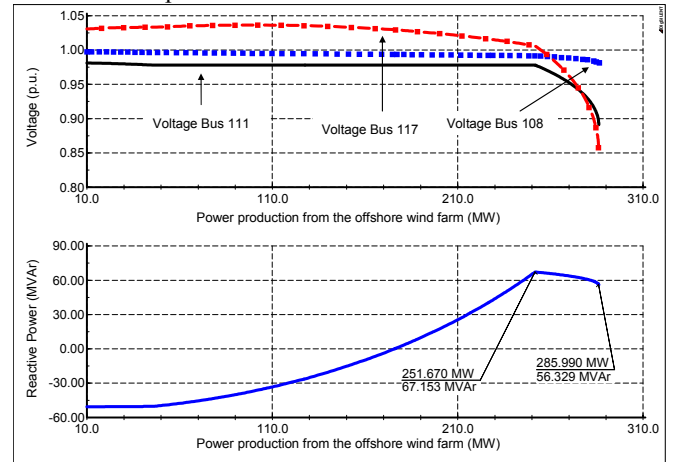


Fig. 7. U/P curves for the offshore wind farm in Fig. 1 and the corresponding reactive power output from the SVC.

For comparison, simulations are made, where the SVC is deactivated, meaning that the reactive power must be supplied by the nearest power plants.

¹ DigSILENT Programming Language

B. Q/U – curves

To analyze, how the compensation of the wind farm affects the voltage stability, a Q/U – plot is made for Bus 116. In PowerFactory, Q/U-curves are made by installing a fictitious synchronous generator with a voltage controller on the bus bar under consideration. With a DPL script, a series of load flows is performed with different voltage set points. The reactive power flow in the branches connected to the bus bar is plotted against the voltage set point of the synchronous generator. When the reactive power output from the fictitious generator is zero, an equilibrium exists. If the derivative of the reactive power output from the fictitious generator with respect to the voltage set point is positive in the vicinity of the equilibrium, the equilibrium is stable, since a small increase in voltage would cause a reactive power deficit on the bus bar and vice versa [10]. Q/U curves for Bus 116 are depicted in Fig. 8. The aggregated induction generator of the offshore wind park has been compensated with a fixed capacitor which provides a power factor of one on the high voltage side of the 33/0.7 kV transformer at 160 MW production and a voltage of 1 p.u. It can be seen that an equilibrium exists at a voltage slightly above 1 p.u. The equilibrium is stable, since the steepness of the Q/U-curve corresponding to the grid is numerically larger than the steepness of the Q/U-curve corresponding to the wind park including the compensation.

If the reactive power compensation method at the wind farm is changed, it will not change the Q/U-curve corresponding to the grid, but the equilibrium might be moved. Therefore, this method can be used to evaluate the influence of the different reactive power sources individually.

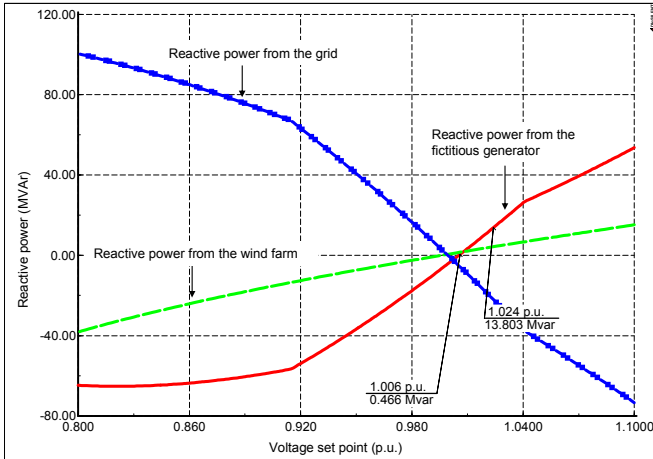


Fig. 8. Q/U – curves for Bus 116 when the offshore wind farm is producing 160 MW and is compensated with a capacitor.

C. Sensitivity analysis

Another way to analyze the behavior near a given equilibrium is to derive the sensitivity coefficients directly from the Jacobian matrix [10]. This is also possible with PowerFactory. Below, the output from the sensitivity tool for Bus 116 is shown:

```
m: dphidP 0.1078452 deg/MW (dphi/dP Sensitivity)
m: dphidQ -0.02477373 deg/Mvar (dphi/dQ Sensitivity)
m: dvdp -0.00005108 p.u./MW (dv/dP Sensitivity)
m: dvdq 0.00138631 p.u./Mvar (dv/dQ Sensitivity)
```

For comparison, dV/dQ in Fig. 8 close to the equilibrium can be estimated as

$$\frac{\partial V}{\partial Q} = \frac{(1.024 - 1.006) \text{ p.u.}}{(13.803 - 0.466) \text{ MVar}} = 0.001350 \text{ p.u./MVar}$$

This is relatively close to the 0.00138631 p.u. / MVar calculated by the sensitivity method.

V. CONCLUSION

A reduced model of a transmission power grid for various analyses of electricity-producing wind turbines and their grid interaction is set up and implemented in the simulation tool PowerFactory (DigSILENT). The model is sharable between all the parties interested in the issues of grid-connection of wind turbines and power grid analyses. The model can be acquired by writing an email to the first author.

The model contains models of central power plants, consumption centers, transmission lines, local wind turbines and a large offshore wind farm. Furthermore, the model can be expanded by models of large wind farms with advanced ride-through solutions for evaluation of these solutions at not-fixed voltage and frequency.

The model has shown to be a very good platform to assess and evaluate the advanced wind turbines models and controllers developed at Risø in the simulation tool PowerFactory. It provides the possibility to understand and to get a realistic insight of the complex dynamic interaction between large wind farms and the power transmission system.

The model has been used for exercises in the course *Stability and Control in Electric Power Systems* at the Technical University of Denmark. The advantage of using a realistic but simplified model of a power system for exercises is that the problems occurring in the real system can be illustrated, while using the state of the art analysis methods provided by PowerFactory.

VI. APPENDIX A

TABLE I
MAIN DATA OF SYNCHRONOUS GENERATORS

Parameters	G1	G2	G3	G4
MVA	750	1400	2500	1500
Rat. Volt, kV	20	20	20	20
Rat. Frequency, Hz	50	50	50	50
Inertia, s	5	5	5	5
X_d , pu	2.43	2.1	2	2.09
X_q , pu	2.33	2	2	2.04
X_d' , pu	0.307	0.365	0.3	0.254
X_q' , pu	0.6	0.7	0.7	0.39
X_d'' , pu	0.2	0.2	0.2	0.2
X_q'' , pu	0.2	0.2	0.2	0.2
X_l , pu	0.15	0.15	0.15	0.15
T_d0' , s	7.5	7.4	6.6	6.6
T_q0' , s	2.5	2.5	2.5	1.3
T_d0'' , s	0.029	0.041	0.04	0.038
T_q0'' , s	0.06	0.08	0.06	0.06
$S(1.0)$	0.1	0.1	0.1	0.1
$S(1.2)$	0.3	0.3	0.3	0.3

TABLE II

EXCITATION CONTROL OF SYNCHRONOUS GENERATORS

Generator	Model	Parameter List			
G1	BBSEX1[11]	Tf, s	0.04	Switch	0
		K	40	VRmin	-6.1
		T1, s	4	VRmax	6.1
		T2, s	1.2	Efdmin	-4.1
		T3, s	0.02	Efdmax	5.3
		T4, s	0.1		
G2	BBSEX1[11]	Tf, s	0.04	Switch	0
		K	140	VRmin	-4.75
		T1, s	12.09	VRmax	5.25
		T2, s	1.37	Efdmin	-4.75
		T3, s	0.02	Efdmax	5.25
		T4, s	0.0565		
G3	SEXS [11]	TA, s	0.2	TE, s	0.16
		TB, s	0.012	Emin	0
		K	1	Emax	5
G4	BBSEX1[11]	Tf, s	0.04	Switch	0
		K	110	VRmin	0
		T1, s	8	VRmax	5
		T2, s	2	Efdmin	0
		T3, s	0.02	Efdmax	5
		T4, s	0.05		

TABLE III

GOVERNOR CONTROL OF SYNCHRONOUS GENERATORS

Generator	Model	Parameter List			
G1 G2 G4	BBGOV1[11]	Df, pu	0.003	T1, s	0.1
		KS	16	T2, s	15
		KP	0.2	T3, s	1
		TP, s	3.5	TE, s	2
		K1	0.05	Ymin	-0.1
		K2	0.7	Ymax	0.1
		K3	0.5	Ptmin	0.25
				Ptmax	1.25
G3	BBGOV1[11]	Df, pu	0.003	T1, s	5
		KS	16	T2, s	0.1
		KP	1	T3, s	0.1
		TP, s	0.1	TE, s	2
		K1	0	Ymin	0.001
		K2	0	Ymax	1.001
		K3	0	Ptmin	0.25
				Ptmax	1.25

TABLE IV
WIND TURBINE DATA

Parameter	Large Wind Farm	Local Wind Turbines
Rat. Power, MW	165	500
Rat. Volt, kV	0.7	0.7
Rat. Frequency, Hz	50	50
Gen. Inertia, s	0.5	0.5
Stator Resistance, pu	0.006	0.006
Stator Reactance, pu	0.08	0.08
Rotor Resistance, pu	0.018	0.018
Rotor Reactance, pu	0.12	0.12
Mag. Reactance, pu	4.4	4.4
Shaft Stiffness, pu/el.rad.	0.6	0.33
Rotor Inertia, s	5	2.5

TABLE V
STATIC VAR COMPENSATOR

Parameter	
Rat. Capacity, MVar	+/-50
Rat. Volt, kV	20
Rat. Frequency, Hz	50
Reactor, MVar	100

Capacitors and filters, MVar	50
Controller Model	CSVGN1 [11]
Controller parameter K, pu	150
Controller parameter T1, s	0
Controller parameter T2, s	0
Controller parameter T3, s	1.009
Controller parameter T4, s	0
Controller parameter T5, s	0
Reactor Min. Rmin, pu	0.03
Controller Min. Vmin, pu	-1
Controller Max. Vmax, pu	1

VII. REFERENCES

- [1] "Wind turbines connected to grids with voltages above 100 kV - Technical regulations for the properties and the control of wind turbines,, Energinet.dk, Transmission System Operator of Denmark for Natural Gas and Electricity, Technical Regulations TF 3.2.5, 2004, 35 p. Available: www.energinet.dk
- [2] J. Matevosyan, T. Ackermann, S. M. Bolik. "Technical Regulations for the Interconnection of Windfarms to the Power System", Chapter 7, in Wind Power in Power Systems, T. Ackermann, Ed. John Wiley & Sons, Chichester, U.K., 2005, 691 p.
- [3] V. Akhmatov, "Analysis of dynamic behaviour of electric power systems with large amount of wind power, Ph.D. dissertation, Technical University of Denmark, Kgs. Lyngby, Denmark, 2003. Available: www.oersted.dtu.dk
- [4] V. Akhmatov, H. Knudsen, "An aggregate model of grid-connected, large-scale, offshore wind farm for power stability investigations – Importance of windmill mechanical system", *Int. J. of Electrical Power and Energy Systems*, vol. 24, no. 9, pp. 709–717, 2002.
- [5] V. Akhmatov, H. Knudsen, A. H. Nielsen, J. K. Pedersen, N. K. Poulsen, "Modelling and transient stability of large wind farms", *Int. J. of Electrical Power and Energy Systems*, vol. 25, no. 1, pp. 123-144, 2003.
- [6] "Specifications for connecting wind farms to the transmission network", 2nd Ed., ELTRA Transmission System Planning, Denmark: ELT1999-411a., 2000.
- [7] Hansen A.D., Michalke G., Sørensen P., Lund T., Iov F. Co-ordinated voltage control of DFIG wind turbines in uninterrupted operation during grid faults, in press Wind Energy, 2006
- [8] Hansen A.D., Sørensen P., Iov F., Blaabjerg F. Centralised power control of wind farm with doubly-fed induction generators, *Renewable Energy*, 2006, vol. 31, pp 935-951.
- [9] Hansen, A.D.; Sørensen, P.; Iov, F.; Blaabjerg, F., Control of variable pitch/variable speed wind turbine with doubly-fed induction generator, *J. Wind Eng.* (2004), vol. 28, No. 4, p 411-432
- [10] Prabha Kundur, *Power System Stability and Control*, McGraw Hill, 1993
- [11] DIgSILENT GmbH, *DIgSILENT Technical Documentation - PowerFactory DSL Models*, August 2006

VIII. BIOGRAPHIES



Vladislav Akhmatov is since 2003 with the Planning Department (Analysis and Methods) of Energinet.dk, the Danish TSO for natural gas and electricity. Before that he worked for the Danish electric power company NES A/S. He has developed detailed wind turbine models for different power system simulation tools and carried out respective analyses. In 2002 he received the Angelo's Award and in 2006 the Electro Award of the Danish Engineers' Society for his work with wind power in Denmark.



Torsten Lund received his M.Sc.E.E. degree at the Technical University of Denmark in 2001. From 2001 to 2004 he worked for Siemens AG - Automation and Drives in Germany where he developed motor control for electrical trains. Since 2004 he is working on a Ph.D. project with the title *Power system operation and control for integration of large scale of wind energy* at Risø National Laboratory and Technical University of Denmark.



Poul Sørensen (M'04) was born in Kolding in Denmark, on June 16, 1958. He obtained his M.Sc. from the Technical University of Denmark, Lyngby in 1987. He was employed in the Wind Energy Department of Risø National Laboratory in October 1987, where he is currently working as a senior scientist and project manager. His main field for research is integration of wind power into the power system. He was a member of the IEC working group preparing IEC 61400-21, and is currently a member of the maintenance team MT21. He is also a member of IEA annex XXI on "Dynamic models of wind farms for power system studies".



Anca D. Hansen received her Ph.D. in modeling and control engineering from the Technical University of Denmark in 1997. Since 1998 she has been employed at Risø National Laboratory in the Wind Energy Department – first as Post Doc., scientist and afterwards as senior scientist. Her working field and research interests are on the topics of dynamic modeling and control of wind turbines, as well as dynamic modeling and control of wind farms and on wind farm grid interaction.



Arne Hejde Nielsen was born in Copenhagen, Denmark in 1953. He is associate professor at Technical University of Denmark. After receiving his M.Sc. in Electrical Engineering in 1978 he was employed as research assistant at the University. In the early eightieths he was at ASEA Central Research and Development Department in Sweden working with motor control and general measurement technologies. Since then he is back at the University where he has worked with as different subjects as electrical materials, microprocessor control and now electric power systems.